BUSAN-GEOJE FIXED LINK PROJECT

Koo, Im-Sig
Director,
GK Project Management
Daewoo E&C
Koois7101@dwconst.co.kr

Yang, Bo-hyun
Site Director,
GK Immersed Tunnel Site
Daewoo E&C
A009485@dwconst.co.kr

Kim, Je-Chun
Design team leader,
GK Project Management
Daewoo E&C
Kjc66@dwconst.co.kr

Lee, Jung-Sang
Manager,
GK Project Management
Daewoo E&C
summit@dwconst.co.kr

Abstract: *The Busan-Geoje Fixed Link is an imprortant infrastructure in the south-eastern part of Korea. The Link is composed of three parts, an immersed tunnel and two briges-both including cable-stayed bridges. The GK immersed tunnel as a part of the Busan-Geoje Fixed Link Project, introduced the immersed tunnel method into Korea for the first time. This challenging project to be completed in 2010 will open a new era to link oceans of the world with optimized design and safety for future use. The immersed tunnel method would possibly suitable for use in construction of a sub sea tunnel from Korea to Japan and from Korea to China that could potentially be built in the distant future. We hope the techniques learned from the Busan-Geoje Fixed Link Project can be applied to further projects in the near future.*

Keywords: immersed tunnel, cable-stayed bridge, challenging project

1. INTRODUCTIONS

The Busan-Geoje Fixed Link is an 8.2km long motorway connecting Busan, Korea's southernmost and second largest city, to the island of Geoje where the Korean big two shipbuilding yard locate on with two normal traffic lanes in each direction. This motorway includes a 3,300m immersed tunnel which is one of the longest immersed tunnel in the world and two cable-stayed bridges each of 2km in length. The immersed tunnel consist of 18 elements and each element is approximately 180m long. The standard tunnel elements E1 to E16 have exterior dimensions of 26.46m width and 9,97m height. The width of element 17 to 18 increased to 28.46m because of climbing lane. This tunnel elements are prefabricated of reinforced concrete in a temporary dry dock and are towed to the site and lowered into final position in a dredged trench and are placed on a screeded gravel bed directly without temporary support. Each of the two bridge sections consist of a cable-stayed bridge and approach bridges. The cable-stayed bridge in Lot 1 is a three pylon cable-stayed bridge with main spans of 230m, while the cable-stayed bridge in Lot 2 is a traditional two pylon cable-stayed bridge with a main span of 475m.

The site locates in an exposed offshore, which is subjected to strong winds, large swell waves and strong tidal currents. These conditions together with the tunnel being at a deepest immersed tunnel ever built and the foundation condition is consisting of a very soft, normally to slightly over-consolidated marine clay, makes the project unique and one of the most challenging immersed tunnels ever built. Due

to these conditions, there is no choice but to have very strict accuracy for operations such as trench dredging, gravel bedding and backfilling works that could induce differential settlement.

Several special methods are develoved and applied to overcome the difficult conditions mentioned above. New accurate gravel bedding equipment developed for this project and deep mixing method applied to improve the soft marine clay are presented in the following paper as part of the foundation of immersed tunnel.

In this paper, cable-stayed bridges are mentioned briefly, and the immersed tunnel which is introduced for the first time in Korea is mainly described

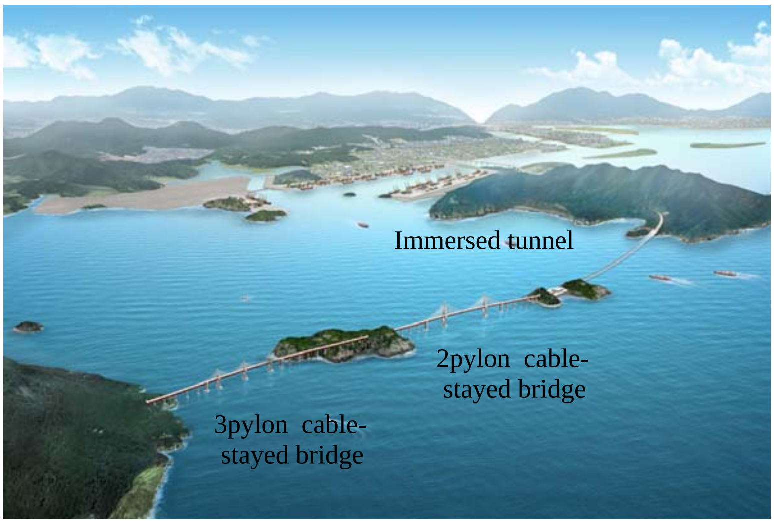

Figure 1. Overview of Busan-Geoje Fixed Link

Figure 2. Aerial photograph of the link under construction

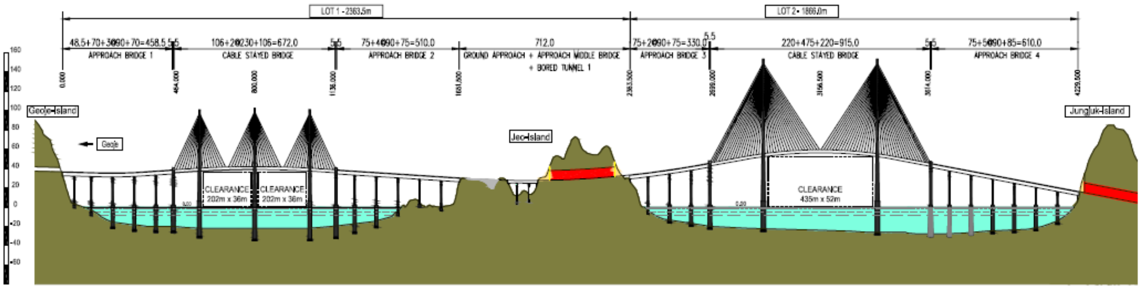

Figure 3. Longitudinal cross section of Lot1 and Lot2

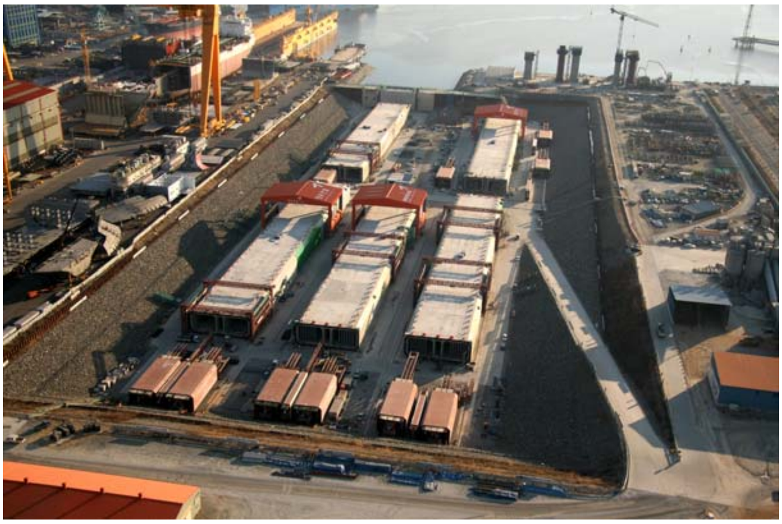

Figure 4. Pre-casting Yard

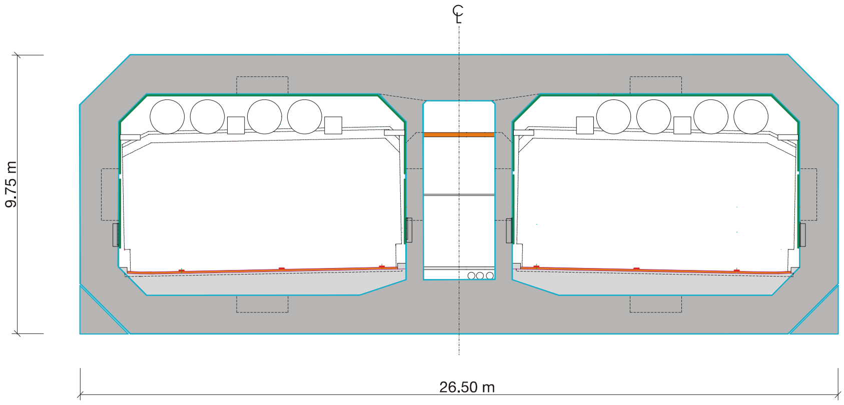

Figure 5. Typical cross section of immersed tunnel

2 BRIDGES

A distinct feature of the bridges is their diamond shaped pylons with curved legs. The curvature of the legs is limited by a no tension criteria for dead load and the use of standard climbing form eqipment. The diamond shape was selected to provide triangulated cable system with improved aeroelastic stability compared to the more traditional H-shape. The shape chosen also makes a compact foundation possible

which is desirable considering the relatively large water depths. All piers and the five pylons except two piers which are founded on the piled foundation are founded on caissons.

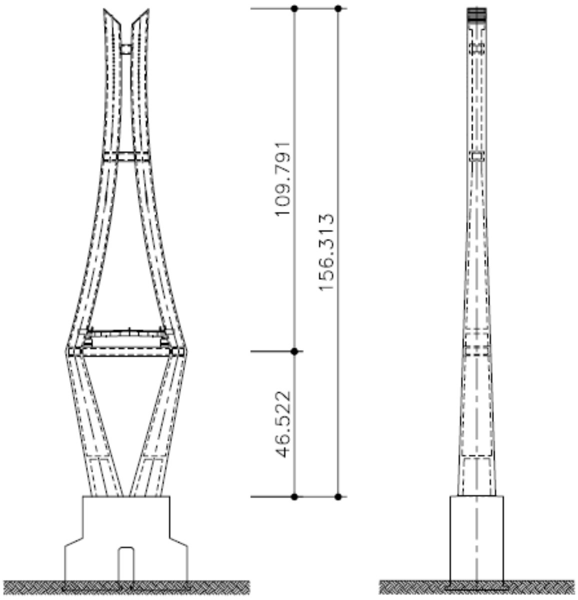

Figure 6. Pylons of Lot2 cable-stayed bridge

2.1 Design loads

AASHTO LRFD code and Korean domestic design standards had been used for the detailed- design. Most of loads were defined by this design code except several load that should consider the local actual site conditions as like wind, wave and ship impact loads.

The bridge site is directly exposed to the South sea and are characterised by strong winds from typhoons and associated high waves. Typhoon Maemi, that strongly hit the Busan area in September 2003 and caused widespread damage. Wave loading had been developed with taking into account the actual bathymetry of the site and developed based on an Extreme Wind Analysis carried out on measured data in the region.

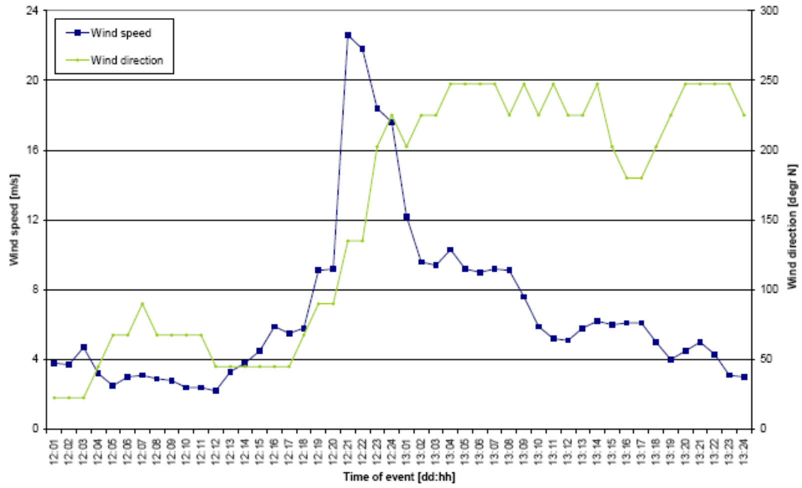

Figure 7. Wind recordings in Busan during typhoon Maemi.

Ship impact loads had been developed with the more general AASHTO requirement that maximum annual frequency of collapse shall not exceed 10^{-4} for the entire bridge.

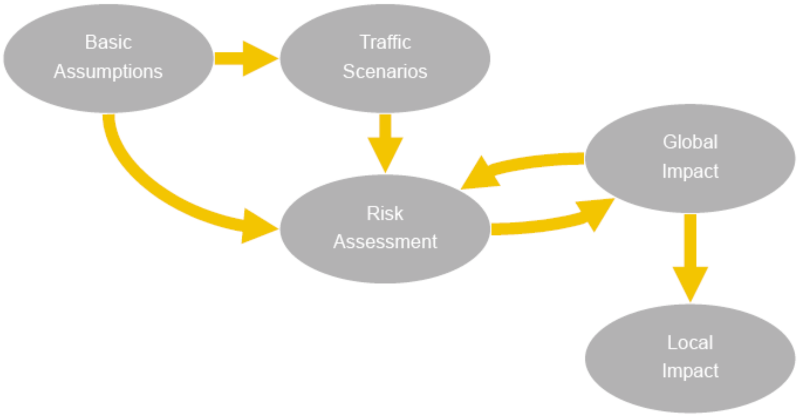

Figure 8. Flow chart for ship collision study

For earthquake loads the AASHTO LRFD approach was followed but it showed that earthquake was not governing load for the design because of the low-level seismic activity (Acceleration coefficient A = 0.154) and good soil condition(Soil type 1)

2.2 Foundation design

All caissons consist of a massive base slab supported by thin wallded cell structure. This type of structure can decrease the stresse transferred in the soil-structure interface.

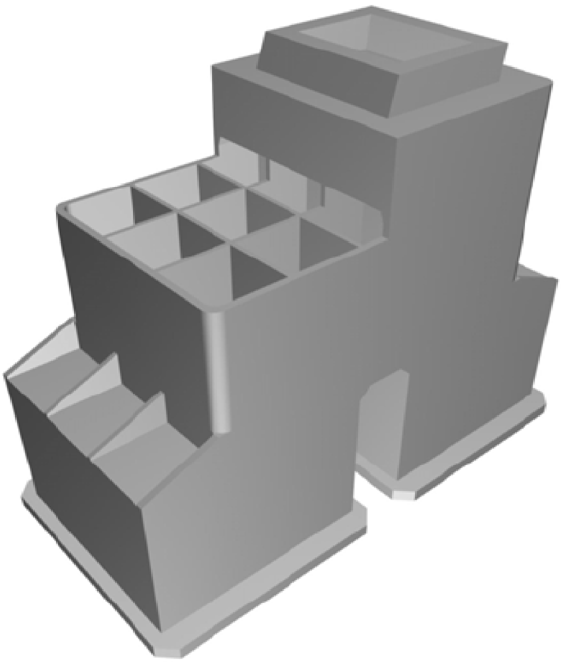

Figure 9. Caisson showing cell structure

All caissons are fabricated on-shore pre-fabricating yard and transported to the site by using a 3000ton floating crane and a 20000ton floating dock. The transported caisson is slowly lowered and

placed on the pre-installed foundation pad and the space between bottom of slab and ground is filled with grout. And then the cells are filled with crushed stones.

Figure 10. Transportation of caisson using FD

The walls of the structure are essentially subjected to compression and shear. The results of the dynamic wind calculations showed large coinciding bending moments around both horizontal axes. This load was to be combined with the effects from wave loads which also resulted in biaxial bending due to the skew incoming angle of these waves relative to the bridge alignment. The effect of biaxial bending from combined dynamic wind and oblique wave loads resulted in an increase of the overall caisson dimensions compared to initial calculations based on an traditional approach with statical wind loads.

3 IMMERSED TUNNEL

3.1 Design Conditions

Below the main effects governing the design of this particular immersed tunnel have been listed.

3.1.1 Hydraulic Pressure

The deepest foundation point of the tunnel is 47m below mean sea level. The water pressure imposes a significant load on the tunnel elements, in particular in the transverse direction. A number of other effects add to the water pressure on the tunnel as can be seen below. The total characteristic pressure can reach an equivalent of 58m water pressure for certain conditions. An increase in the mean sea level of 0.4m has been included due to the global warming.

3.1.2 Waves and current

Most waves at the project area are generated by winds in the area including tropical storms and typhoons. Waves generated by distant storms can also reach the tunnel alignment from southerly directions: these are called swell waves and are not associated with winds in the area. A number of typhoon pass through the project area located in the southern coast of Korea every year. The impact on the structures and artificial islands of the project from typhoon is potentially severe because the link lies in exposed offshore. The deep water wave height generated by typhoon and swell waves can reach 9.2m for a 10,000 year return period. Result from the numerical wave modelling show that the significant wave height is about 0.4 m and 0.8m at the most exposed location along the tunnel alignment. Tidal range varies between 0.8m and 1.6m. The maximum near surface current spring tide is about 0.8m/sec, reducing with depth to 0.6m/sec at near bottom. The predominant current direction is perpendicular to the tunnel alignment.

3.1.3 Earthquake

The Busan metropolitan area is classified as a seismic zone I based on the result of seismic hazard analysis as specified in the Korean Standard Specification of Highway Bridges. Therefore, in this area the corresponding seismic zone coefficient for a 500 year return period is as noted in below Table 1.

Seismic Zone	I
Zone Coefficient	0.11

Table 1. Seismic Zone Coefficient

The risk coefficients representing the ratio of effective peak ground are listed in the following Table 2.

Return Period(year)	500	1000
Zone Coefficient	1	1.4

Table 2. Risk coefficient

The acceleration coefficient (A) of ground motion in the site is calculated by multiplying seismic zone coefficient by risk coefficient.

3.1.4 Ship impact

The Southern coastline of Korea has a large volume of sea going traffic including containerships, gas and oil tankers. Militarily it is an important and strategic area. Overall design of the Busan-Geoje Fixed Link Project considered loadings from impact and sinking of a 50,000 ton vessel sailing to a neighbouring port. A particular safety feature is that the minimum clearance from sea level to the top of tunnel’s rock protection is more than 20m, which is well in excess of the 15m maximum draft of a 50,000 ton vessel.

3.2 Soil improvement

On the basis of the borehole data and seismic reflection survey results a ground profile of the tunnel area been made as below feature. Marine clay is forming the sea bed except in the near shore areas where bed rock outcrops. The thickness of the marine clay along most of the tunnel alignment exceeds 20m. The major part of marine clay is “very soft to soft” and of “very high plasticity” to “extremely high plasticity”.

The segmental type of tunnel chosen for this project is sensitive about differential longitudinal settlement. Therefore, a number of soil improvement methods were considered in order to provide an appropriate foundation for the type of immersed tunnel chosen for the project. These methods included steel pile, sand compaction pile and cement deep mixing. The final foundation concept was to strengthen the clay with mixed cement/clay columns and walls formed by continuous columns, i.e. cement deep mixing (CDM). This form of foundation has previously been used in Korea. It is also in widespread use in northern Europe for the control of settlements of structures built on soft clay deposits.

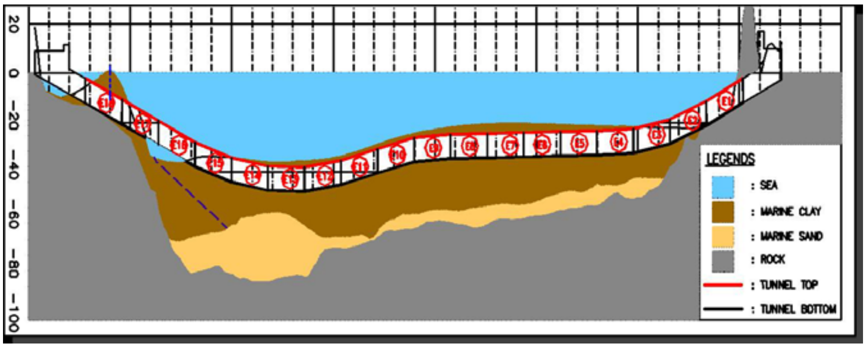

Table 3. Ground profile

Different foundation support alternatives have been investigated through the sensitivity analysis and it was concluded that the most robust and efficient solution is to install settlement-reducing CDM elements. These partial depth CDM columns transfer the vertical load from the base of the tunnel through a gravel bed and the CDM-reinforced clay layer to stiffer, less compressible soil layers as below figure.

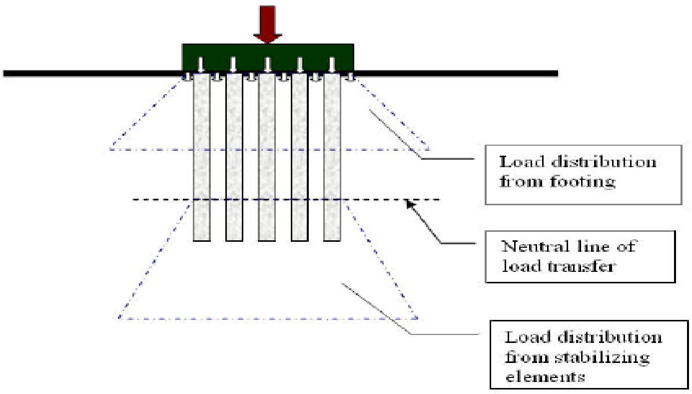

Figure 11. Concept of load sharing between foundation footing and settlement-reducing elements, (Massarsh,1997)

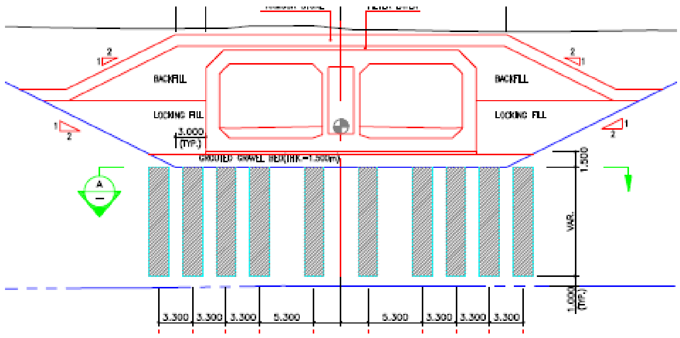

Figure 12. Typical cross section of CDM

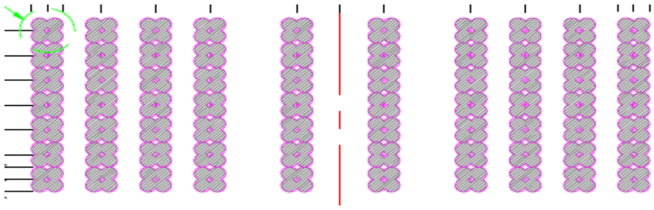

Figure 13. Plan view of CDM

Mixing equipment must be operated under a stable working condition because the Cement/clay mixing column can be damaged by movement of mixing shaft. Therefore, the special offshore equipment developed for this project and this equipment carried out the CDM work successfully under the exposed offshore condition.

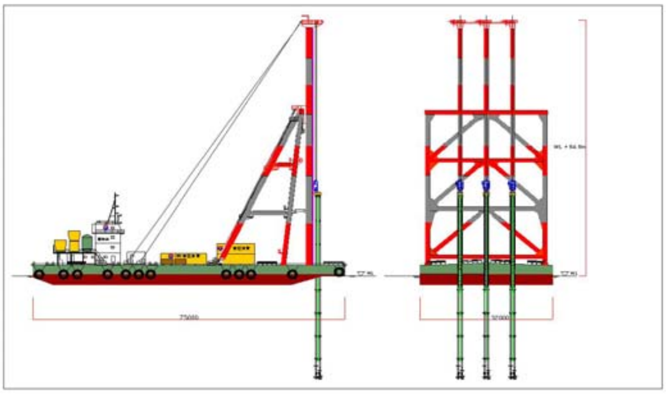

Figure 14. Offshore mixing equipment

3.3 Gravel bed foundation for tunnel

The construction of marine structure foundation consisting of a flat layer of material suitable for immersing tunnel elements or caissons has always been difficult due to constraint of time and strict requirements for accuracy of construction. Several methods using sand or grout underfilling have been applied. In this methods, a tunnel element is initially placed on the temporary hydraulic support after that, a sand-water mixture or grout is injected into space between bottom of element and dredged trench through a pipe system until enough pressure has been built up to support the element sufficiently. However, experience has shown this method have difficulties and disadvantages as mentioned below.

- Full ballast and stability of the element are only reached after completing the underfilling ; element safety can be endangered in severe offshore conditions such as high current and heavy ship traffic.

The alternative method called scrading overcome above mentioned disadvantage by using gravel. The concept of scrading is to deposit the material and level it simultaneously. Material is fed to a fall pipe, the end of fall pipe is positioned and kept at the desired depth. At first material will start to build up under the fall pipe until it reaches the end of fall pipe. Then the material starts to accumulate in the fall pipe as a stone column. By continuously maintaining material in the lower section of the pipe while shifting the pipe sideways, the deposited material is levelled by the end of fall pipe. Thus, the material can be deposited and levelled in one process. This method has proven accurate, reliable, and has reduced construction time on several projects, while this method has a necessary and sufficient requirement to secure an equipment which can do a stable and accurate work in exposed offshore condition. The special equipment was developed for this project because Boskalis's vessel used for the Oresund project could not available.

Trial test to verify a feasibility of scrading concept was carried out in onshore as below feature before starting the development of equipment. The result of this trial test showed that the scrading method can make even gravel bed foundation. Offshore trial test at site also was successfully carried out using a modified gravel bedding equipment. The result of this trial test was that the scrading system accuracy is better than the given accuracy ±40 mm. A very accurate work can be carried out because this work using jack-up barge would not be disturbed by the sea weather condition.

Figure 15. onshore trial test

Hydraulic jack-up barge was modified to suit an exposed offshore work. Dimensions of modified equipment are 61m length and 36m width. Maximum 33.5m length gravel bed berm can be made at one time travel of the fall pipe. Maximum number of the gravel bed berm can be made at one setting of the barge depend on the maximum allowed travel length of the bogie. This travel length can be sufficiently extended by modification of the barge.

Figure 16. Full view of the gravel bedding equipment

The fall pipe was mounted on the bogie which can move on the rail. Length of the fall pipe can be adjusted by rear end of the fall pipe controlled accurately by hydraulic jack.

Figure 17. Fall pipe is mounted on the bogie

Figure 18. rail for travelling of the bogie

All the main equipments can be controlled by computer in central control room. All the important information which show the status of bedding are displayed on the monitor equipped in the control room.

Figure 19. Main control room

The gravel bedding work was done within the given tolerance up to ±40mm have been verified by survey carried out in the tunnel after immersion.

3.4 Immersion

Immersion of the heavy tunnel elements is a challenging operation, especially in exposed offshore, requiring both a close integration of the structural design and temporary work design, and strict procedures and controls during operation at sea.

The following main factor were developed in order to perform the immersion successfully.

- Inject air in the immersion chamber
- EPS (External Positioning System)

Immersion details

In parallel with preparation at the immersion site at the mooring area, all equipment and facilities for immersion are installed and the element is prepared for transportation by tug boats to the immersion site, on the shore of Gaduk island. In order to accurately predict the marine conditions during transportation, a local weather forecasting system has been installed at the site, the first of its kind in Korea. A 5 day period with waves less than 0.4m high is needed during transportation, immersion, connection and stabilization of each tunnel element. Once this 5 day window is confirmed by the weather forecasting system, a decision to “Go” for transportation and immersion can be made. Once the element arrives at the immersion site, it is connected to pre-installed anchors and wires to stabilize it against waves and current. After increasing the weight of tunnel by increasing water in the internal ballast tanks, the element is immersed under the control of a positioning system and adjusted by the connecting wires to its correct location.

Figure 20. connect wires to pre-installed anchor

The element is placed about 50cm behind the previously installed element. After that, final connection work is prepared. At first, pulling jacks are installed between the previous element and the new one. Then, the tunnel is slightly lifted by a steel frame structure installed outside the element, called External Positioning System (EPS) to reduce friction force between the gravel bed and the underside of the element. The EPS is an external jacking system in a shape of a portal frame, which is connected at the TE. The EPS consist of two legs with a load spreading foot on the end of each leg. The horizontal jacks attached at the foot are used for the realignment procedure. This frame is suspended to the lifting lugs of the TE. Two EPS are used at both primary and secondary side.

Figure 21. 3D view of EPS frame

Once the friction force is overcome with EPS, the element can be pulled to the connection surface of the previous element by pulling jacks'. When connected, the rubber joints installed at the end of the new element are firstly compressed to seal a space between temporary bulkheads to prevent ingress of sea water. After confirming the 1st connection, entrapped sea water between the bulkheads is de-watered by opening the immersion chamber valve on the bulkhead of the previous element. Before the de-watering start, some volume of air is injected through valve attached on the bulkhead at the secondary end of the previous element to prevent a sudden decrease of pressure in the chamber because if pressure in the chamber decrease dramatically, Gina gasket can be deformed in the direction of inside due to difference of pressure between chamber and outside during the de-watering.

After connection, the final correct positioning is done by the EPS. Then, 2nd rubber joints, Omega Seals, are installed inside the elements. Backfill and Rock protection are installed to protect the tunnel against external impact such as from a sinking ship, ship collision, and falling or dragging anchors. After de-watering and dismantling of the ballast tanks, ballast concrete is placed inside the tunnels to prevent lifting and movement of the tunnel and all the construction activities are finalized by doing pavement works.

The eighth element was immersed successfully in February 2009. The ninth immersion is being prepared at the mooring area now. We have enough confidence to proceed with remain immersions without any delay because we have managed to overcome many obstacles until now.

4 CONCLUSION

Busan-Geoje Fixed Link locates in an exposed offshore, which is subjected to strong winds, large swell waves and strong tidal currents. Thus, the design and construction conditions are very chanllenging and a number of traditionally used solutions for immersed tunnels not usable. Therefore, the design and construction have been developed in order to overcome a number of difficult conditions. The last immersion for element 18th is planned in middle of 2010 and the link is scheduled to open for traffic in the end of 2010.

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